Guidelines for Progression of PBL Competencies

In Engineering and Science Education

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IN ENGINEERING AND SCIENCE EDUCATION

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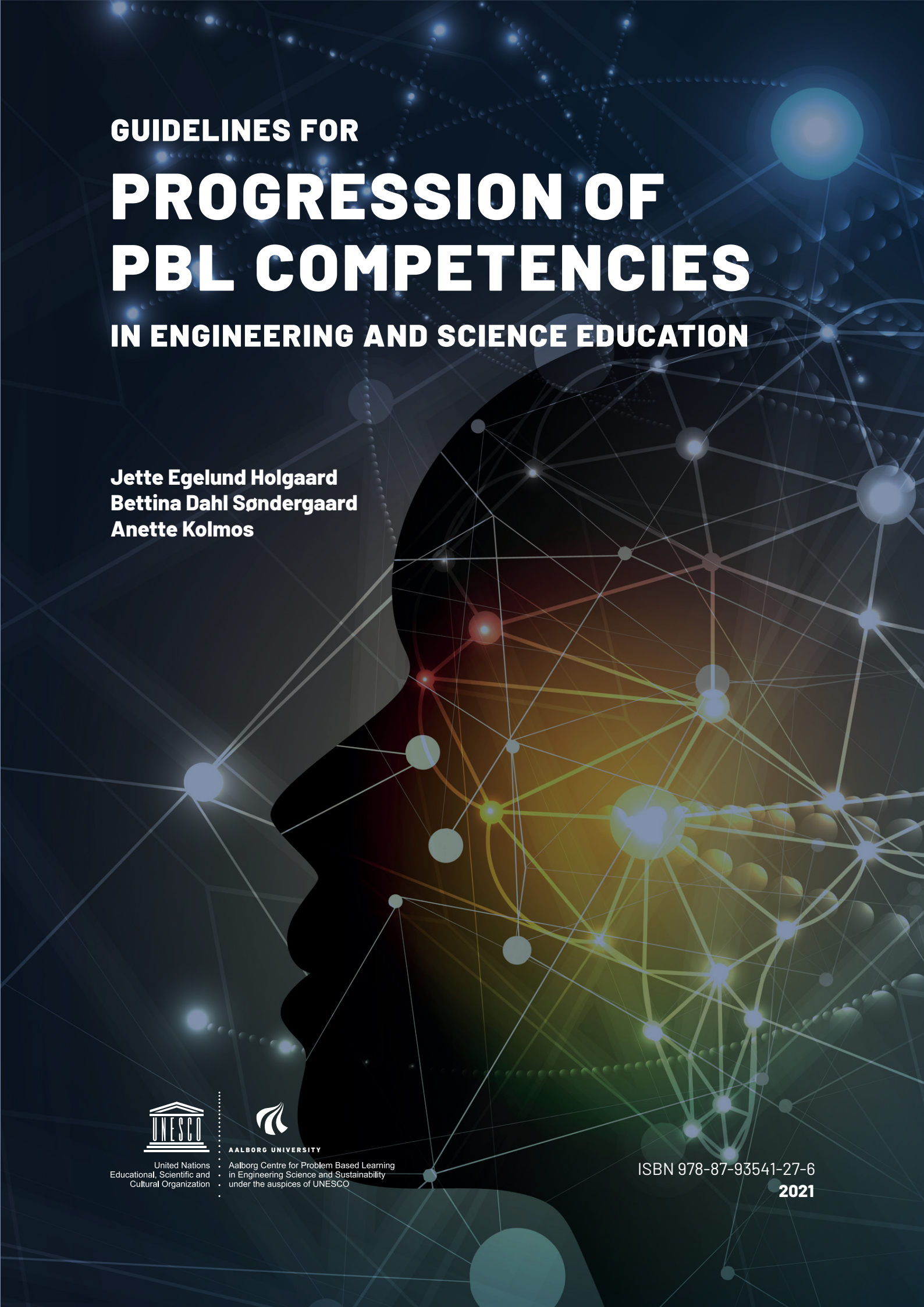

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1. INTRODUCTION

The Danish Qualification Framework for Higher Education states that competencies are the capability to work responsibly and independently and have the ability to apply knowledge and skills in a work situation or a study context. Thus, there is an integrated taxonomic understanding that competencies are based on knowledge 'about something' and the ability (skill) to 'do something', and 'competencies' add a dimension of being able to judge and arrange independently when to do what, using what knowledge and, not least, to know when new thinking is needed.

In a taxonomic sense, competencies require already acquired knowledge, procedures and methods to be applied to new situations, and the problem field is situated in these new situations. The problem field could arise from an unsatisfactory situation, a situation with untapped potential or from a more fundamental wondering about situations where risks and potentials are still unknown. A problem-based learning environment thus requires the highest taxonomic level. Therefore, PBL progressive learning goals for problem-based and project-organised learning (PBL) are based on the PBL competencies, which we will describe below.

This document starts with a more theoretical section on PBL competencies and how they are acquired, followed by a practical section with ideas for concrete ways in which teaching can be designed to allow for the acquisition of the above-mentioned competencies. The aim is to support study environments for higher education programmes in engineering, science and mathematics at Aalborg University in their work with progressive learning goals within PBL, but we hope that the catalogue can find even broader application outside Aalborg University and Denmark.

2. WHAT ARE PBL COMPETENCIES AND PROGRESSIVE LEARNING GOALS?

The introduction described that competencies include knowledge 'about something' and the ability to 'do something' in a specific situation, and this 'something' emphasises that competencies are always related to something. In this context, there is a focus on PBL.

2.1 PBL competencies

The PBL Academy at Aalborg University has defined four fields of competency within PBL (AAU PBL Academy, 2018), summarised here as:

- Problem-oriented competencies, which are the relationship between students and the problem.
- Interpersonal competencies that characterise the relationship between the student and other people such as fellow students, supervisors, external partners, etc.
- Structural competencies that characterise the relationship between the student and the tools/methods used to structure the problem-based learning process.
- Metacognitive competencies that characterise the relationship between the student and the learning process, which supports, connects and creates new thinking in the three above-mentioned competencies.

The interpersonal (between people) and the structural (people in relation to tools) competencies can be summarised in a single concept as process competencies – that is, competencies focussed on handling the process of problem-oriented work. It should also be noted that metacognitive competencies are relevant across the first three competencies.

To this framework, we want to add that there is a cross-cutting digitisation competency that is related to the PBL competencies. Although the idea of digitising the education sector is present in both PBL and more traditional learning environments, the pedagogical model will have strong implications in terms of how digital competencies come into play. Therefore, we will also address digitisation competencies as a natural element of the PBL competencies of today and, not least, the future.

Figure 1 summarises the four PBL fields of competencies, specified with examples of themes under each competency.

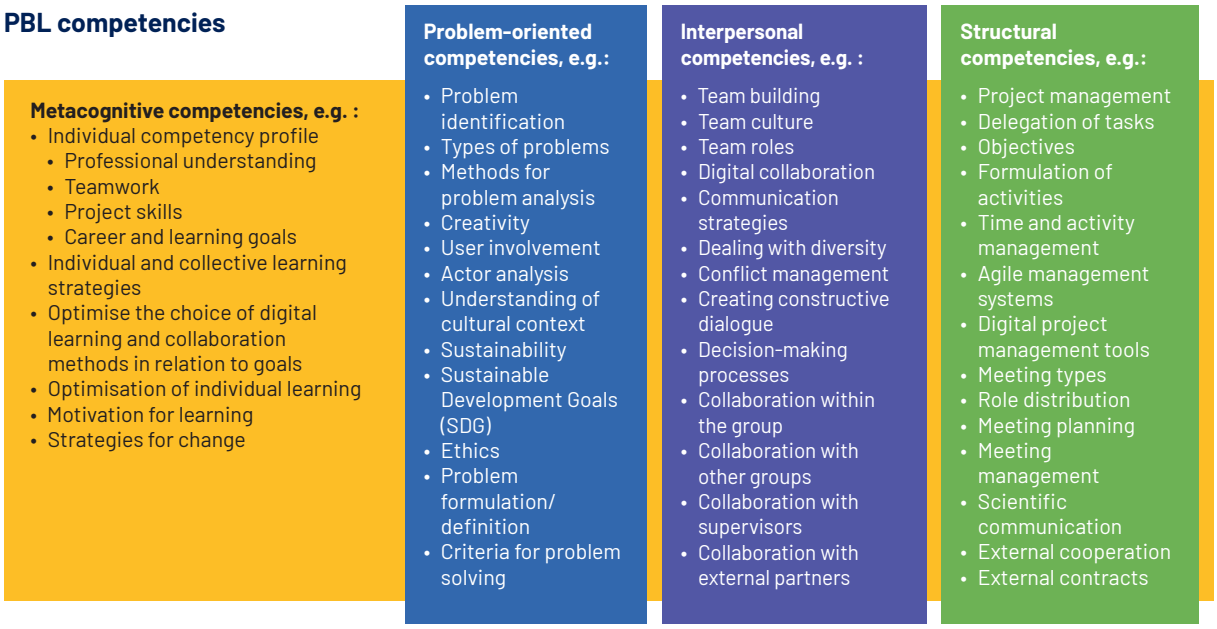

Figure 1: PBL competencies specified and with elements of the digitisation competence.

2.2 How do you acquire PBL competencies?

PBL competencies include practical skills. Thus, they cannot be learned using a purely theoretical approach; they imply that the student has experience on which to build. It is not enough to know theoretically how to manage a project if you do not have experience with how many bothersome and non-linear loops you have to go through to establish progression in a project. On the other hand, it is also not enough to have only 'raw' experience without reflecting on it and then relating the experience to more general theoretical models. If you only have experience without reflection, you usually end up in a trial-and-error process with no articulation on how the process went. Here, it is also important that theoretical models are used during the reflection to make it qualified and articulated, rather than driven by intuition and tacit knowledge.

There is no doubt that, in many ways, the development of engineering practices is characterised by an ongoing reflective practitioner, but this is precisely where there is a danger that students will end up in a trial-and-error process. For a continuously reflective practitioner, learning necessarily implies that there are structured reflection loops that allow for continuous reflection.

Structured reflection can take many forms. There is deductive reflection, where theories, models, and concepts are used to understand and analyse practical experiences. There is also the reverse process of inductive reflection, based on comparative analysis of experiences and the formation of understandings as a starting point for understanding theory. The ideal is that both types are used to connect experience and theory to achieve a deeper level of understanding.

Acquiring PBL competencies therefore depends on two factors: on the one hand, the PBL practices experienced by students and, on the other hand, how students reflect on their experiences and develop strategies for improvement. It is the interaction between these two aspects that can form the basis for acquiring PBL competencies.

Kolb's learning cycle (see Figure 2) explains how individual learning occurs. Generally, there are four phases, and you usually start by getting some 'experience' in practice. Students could, from a PBL perspective, gain these experiences from the problem-oriented, the interpersonal or the structural competencies. Negative experiences are considered as essential as experiences of success.

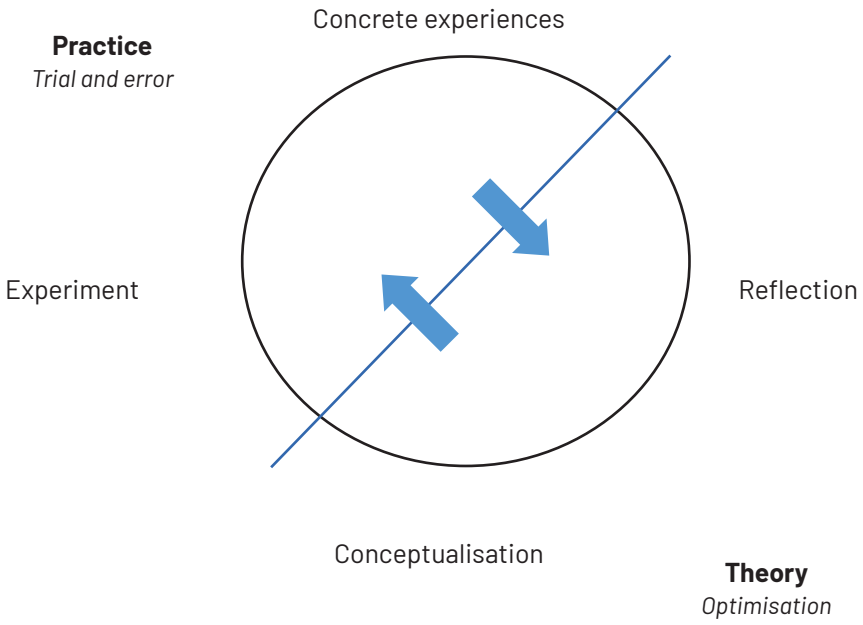

Figure 2: Interplay between practice and theory in experiential learning (based on Kolb, 1984).

Kolb's learning cycle is completed clockwise, so after 'concrete experiences' comes 'reflective observation', that is, reflection. For this reflection to be qualified, it is necessary to apply theory, and this is where a supervisor, consultant or teacher has a role in proactively bringing relevant theory into play, and also facilitating students' reflection, including their abstract conceptualisation. This conceptualisation is a kind of conclusion to the reflection. This conclusion should then lead to 'active experimentation', where new measures are tested or there is an explicit and justified decision to continue the practice as has been done so far, because this is expected to work again. Later, students gain concrete experiences with the new measures and then complete the cycle again.

This 'loop', which connects different concrete experiences, should ideally be completed several times per semester, but particularly towards the end of a semester. You can also talk about a 'double loop' when students not only reflect on how it went, but also on why it went the way it did, and more fundamentally question their current patterns of action and values for the project work. This means that student have to reflect on a number of previous reflections and conceptualise, for example, how they generally interact with each other in a project, or how good they really are at reflecting and conceptualising. Finally, during such 'double-loops', metacognitive competencies are developed (Argyris, 2005).

It is therefore important with a different PBL practice to provide a framework for students' PBL experiences. This can be created through a variety of open/closed problems, external/internal problems, project scopes, project types, coherence between courses and projects, digital/face-to-face co-operation, reporting types, exam forms, etc. In other words, it is essential to create opportunities for students to experience diverse collaborative and project processes, which we describe in more detail in section 3 on teaching and learning activities and exam forms.

Similarly, it is important to create opportunities for reflection. There are different approaches to reflection, and it is beneficial for students to apply a variety of these approaches. A characteristic difference between reflection methods lies in whether:

- they take place continuously during the process as a reflective practitioner;
- time/resources have been devoted to structured reflection; and
- students are accountable for their reflections.

The difference will be reflected in how consciously reflection is done, because only by conscious reflection is it possible to move to the next step in Kolb's learning cycle. This relates to conceptualisation because it is inherently difficult to conceptualise the unconscious. Conceptualisation helps qualify the groups' future active experimentation with their project work, and it is in this step that the professionalism of problem-based project work can be achieved.

2.3 What are PBL progressive learning goals?

The above review hopefully makes it easier to establish what is actually meant by PBL progressive learning goals. First, these are learning goals that focus on the development of PBL competencies (see Figure 1). Second, they are learning goals that focus on an experiential learning process, combining theory and practice in problem-based project work. Third, the learning goal expresses a progression that relates to several experiences with problem-based project work, and this requires a balance between continuity and variety.

The following is a catalogue of various tools that can be used to create this balance. Continuity is found by maintaining focus on problem orientation and project organisation, and on the principle that teaching activities should support the project. We will focus on various tools that can support variety.

3. WHAT TOOLS CAN BE USED?

Below are tools for working with progressive PBL learning goals that relate to creating variety in problem-based project work by introducing different types of problems, collaborations, projects and forms of reflection, as well as by creating variety in the way problem-oriented project work is documented, measured, supported and tested.

3.1 Variety among problem-based projects

Traditionally, most semesters at Aalborg University have had the same kind of projects: 15 ECTS (European Credit Transfer System) credits where groups have worked internally among themselves with a supervisor, and occasionally with an external partner outside the university or other project groups within the university. By working with different types of problems, collaborations and projects, students will have the opportunity to gain broad experience that includes different types of PBL competencies, and by working with different types of reflection, students will be able to develop these competencies in a qualified way. Figure 3 shows an overview of the ways in which the problem-oriented project can be varied and how this can generally be assumed to contribute to the development of different competencies.

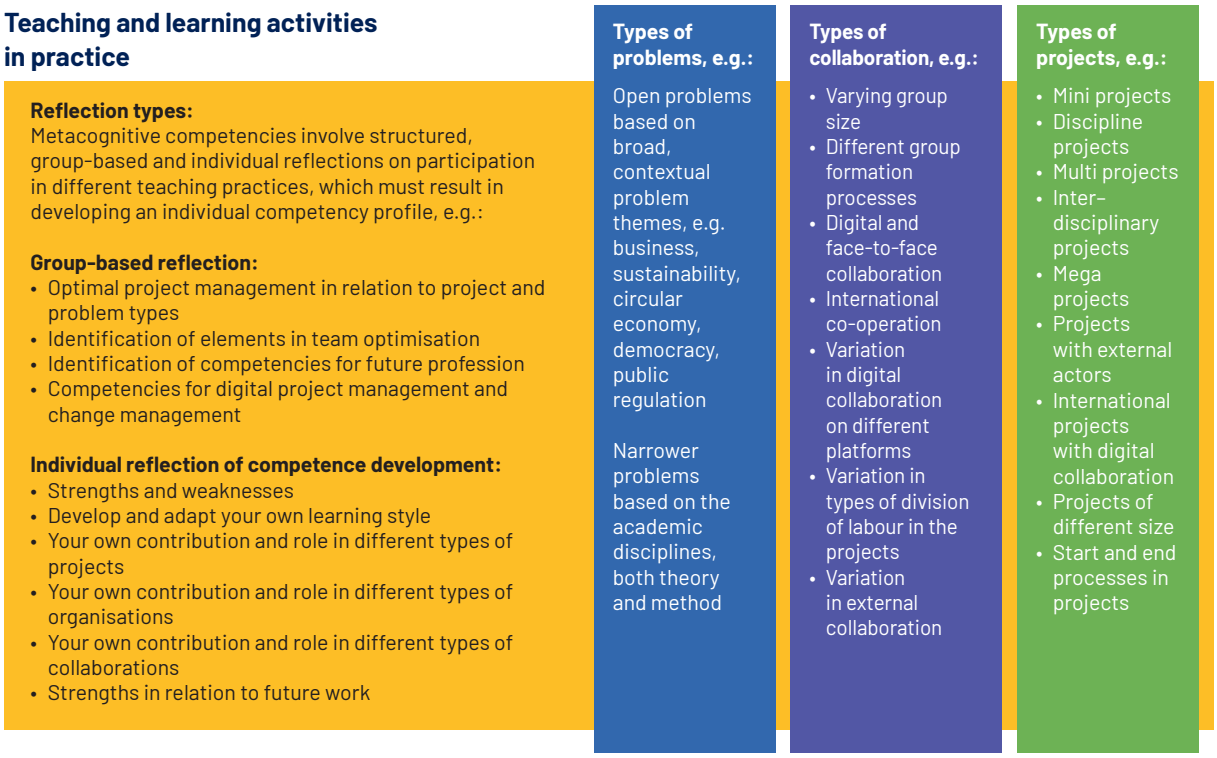

Figure 3: Different types of projects that give rise to the development of different PBL competencies.

Different kinds of project organisation can be set up. Fundamentally, these types can be grouped according to two dimensions (see Figure 4). One dimension concerns whether the project is organised within a group of students or across groups of students or groups of external parties. The second concerns whether the project is primarily monodisciplinary or interdisciplinary. Within each of these types of projects, students will experience having to work on different types of problems. The forms of co-operation will be different, and hence so will the choice of tools and structures.

Interdisciplinarity is a concept that is applied to projects that are not mono/single disciplinary. However, the use and definitions of this term varies and several types of interdisciplinarity are possible, with only one of these types being called 'interdisciplinarity'. Figure 5 shows different aspects of interdisciplinarity using the following concepts: multidisciplinarity, where similar disciplines co-operate; crossdisciplinarity, where one discipline supports the other; interdisciplinarity, where students operate in the borderland between two disciplines; and transdisciplinarity, where disciplines as such are called into question (this can also be done on a more abstract level, so that students are made aware of the possibilities and limitations of disciplines).

For the sake of convenience in this document, we use the term interdisciplinarity in the overall understanding of the term, that is, when more than one discipline is applied. PBL projects can be imagined within many types of disciplines, and here too, there should be variation throughout the programme, partly to develop PBL competencies, but also to prepare the student for the labour market, which will involve interaction between professional competencies.

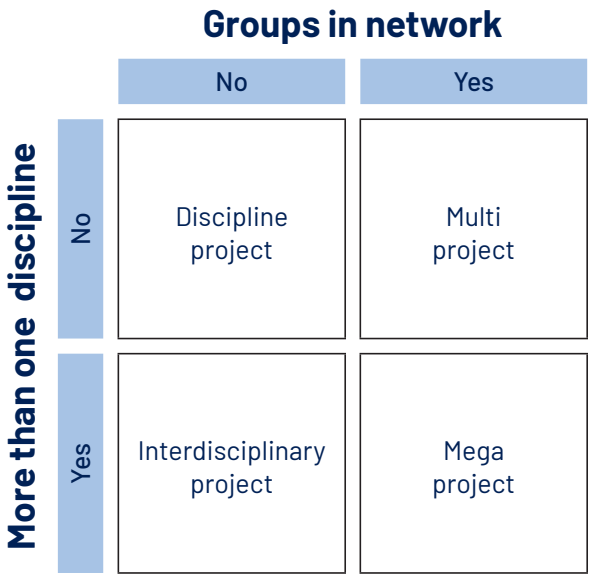

Figure 4: Relationship between different types of projects.

TERM	TYPICAL UNDERSTANDING
(Mono/single) disciplinarity	Just one discipline in play
Multidisciplinarity	Disciplines work together on equal footing without adjustment (friendly interaction)
Crossdisciplinarity	The disciplines are adjusted, one is the support discipline for the other – co-ordination
Interdisciplinarity	Borderland between two disciplines
Transdisciplinarity	Dissolution of original disciplines – new discipline – involvement of stakeholders

Figure 5. Different types of interdisciplinarity. The concepts are based on Petrişor (2013).

The two dimensions, interdisciplinarity and networking, give rise to clear analytical distinctions (yes/no) between four project types:

- The discipline project, which aims to socialise students into a given discipline based on a confined and fairly well-defined problem field.
- The multi project, which aims to teach students to work across teams within a defined problem field towards a common goal, where everyone has the opportunity to give mutual, qualified feedback.
- The interdisciplinary project, which can teach students to work across disciplines by addressing an open but relatively defined problem field in a group of students from several fields of study.
- The mega project, where there is an opportunity to teach students to work with open and complex problems that are also addressed from different disciplines with regard to problem solving, as well as an opportunity to gain experience with communication and collaboration across subcultures.

As appears from the above review, different types of problem-based project work will provide different opportunities for PBL learning goals.

3.2 Different types of documentation of the project work

Regarding documentation of the project, the tradition at Aalborg University has been to prepare a written report followed by an oral presentation with associated slide material. The report has been the norm and the foundation, to which it has been possible to add other documentation, such as a physical product, a video, an article or a poster. However, it should also be mentioned that several education programmes at Aalborg University have experimented with completely replacing the written project report with other media. The point here is to show that there can be variety in the communication of the problem-based work itself, an endeavour that might provide fertile ground for developing students' communicative competences. Moreover, for different types of projects, it is far from certain that the traditional report will be the optimal choice.

Here too, variety can be created, for example, between:

- Written project report (project results and process analysis)
- Article in the style of a research paper
- Hardware with an associated manual, if any
- Software – application, with associated process documentation
- Sketchbooks (including design, process diagrams, mind maps, etc.)
- Video
- Games
- Slides
- Items
- Career plan
- Other

These forms of reporting will in turn give rise to the development of both professional and PBL competencies.

3.3 Different types of learning goals

The development of learning goals implies an intentional but also, in this context, institutionalised approach to learning. This means that the learning goals are a means of creating room for action for students in which they themselves are responsible for navigating. The learning goals become even more open when students are given greater space for action. For example, a learning goal that prescribes knowledge of theories within a specific domain provides more room for action in the choice of theory than a learning goal that prescribes knowledge of a specific theory.

Convergent (delimitating) learning goals are integrated into the curriculum to ensure that students get through the material that defines the specific discipline. Conversely, more divergent (open) learning goals help to ensure that students can work on authentic issues, where their primary relevance is defined not by the learning outcome of the student, but by their topicality and the needs of the world outside the university. Where the convergent learning goals aim to build knowledge and abilities, the divergent learning goals are more about building competencies.

In the preparation of learning goals aimed at PBL competencies, it is therefore essential to consider the balance, but also the coherence, between convergent and divergent learning goals. For example, if you want the student to have knowledge of various theories and methods of conflict management, you can work towards a more divergent formulation by replacing 'conflict management' with co-operation. Conversely, you can work towards a more convergent formulation by choosing 'active listening' instead of conflict management, thus focussing on a particular method with associated theory. By playing with the divergence of the subject field and comparing it to the desired skill profile, you can often find the appropriate level depending on the purpose. You should also keep in mind that convergence–divergence is also a way of creating progression – for example, you can start off very delimited (convergent), merge and, on that basis, create divergence. Conversely, we can start more openly (divergently), deconstruct and, on this basis, create convergence.

In addition to the fact that the subject area of the specific learning goals can be more or less delimited, the type of learning goals can also vary greatly through the action-bearing verb. In other words, what is it that we want the student to do? Should the student exemplify, reflect on, analyse, discuss, plan, evaluate, identify appropriate theories and methods, experiment, optimise, evaluate, compare, nuance or transfer? Moreover, from a perspective of progression, when does the student have an experiential basis that makes it possible to make demands for a given mode of action? For example, if students want to reflect on how different group setups can give rise to different conflict resolution strategies, then experience with working in different groups in a problem-oriented project could significantly help students in achieving this learning goal.

Last but not least, the individual learning goals are complex, where complexity is understood as the number of subject areas and forms of action mixed together in one and the same goal. Again, this is a balancing act between several simple goals and a few complex goals. A few simple goals will rarely provide enough learning depth to qualify a module, and this situation is therefore relatively rare. Conversely, there is a risk of constructing too many complex goals, which signals a high level of ambition, but often translates into more superficial learning. These risks are certainly not reduced in the development of learning goals targeted at PBL competencies, as the time students have available to meet such generic learning goals can be difficult to quantify. The important thing, however, is that the time students need to spend on meeting these learning goals does not end up as a 'blind spot' (i.e. something they do while doing something else) or a 'black spot' (i.e. something they do while they really ought to be doing something else).

As always, there needs to be an alignment between the defined learning goals, the organised educational activities and the chosen form of examination (Biggs & Tang, 2011). Work on these three elements should be seen as an iterative process, because the development of the supporting teaching activities and the testing of the objectives can help balance the focus, mode of action and complexity of the learning goals.

3.4 Different types of supporting teaching activities

It is central to the perception of progressive PBL learning goals that there are a number of supporting elements. However, not all teaching activities need to be organised as traditional courses in a particular ECTS format. In addition to such courses, you can plan 'just in time' teaching activities over a number of themes, such as workshops, presentation seminars or a number of online resources, that students can visit as needed. Figure 6 shows an overview of possible themes in such teaching activities.

In planning these teaching activities, it is essential to achieve coherence between the activities that primarily support practice and theory in Kolb's learning cycle. This interaction is fundamental in order for students to complete the full cycle of the experiential learning process. A juxtaposition of such supporting elements is:

- an introductory PBL course in the first semester – or continuously over a long period of time;
- co-operation with a consultant who contributes with a research-based approach to PBL;
- ongoing knowledge exchange during group co-operation, including status seminars during the semester and discussions of process analyses;
- semester co-ordination framing the type of the problem-based project;
- supervision that, based on a principle of apprenticeship, contributes to the development of problem-based learning practices related to the discipline; and
- where possible, company co-operation, which provides an experiential basis for transferring PBL competencies from an academic to a business context.

While the first two points are based on the theory side of Kolb and link this to practice, the three subsequent points are based on the practical side of Kolb, with the inclusion of relevant theory. During and following the basic module, the consultant can support the course 'drip by drip' by systematically inspiring and ensuring reflection and development of the students' PBL practices. The following are examples of different types of consultant activities that can support the progressive learning goals. These examples include what content can be linked to the different types of consultant activities and how these can be combined into a multi-semester consultant process.

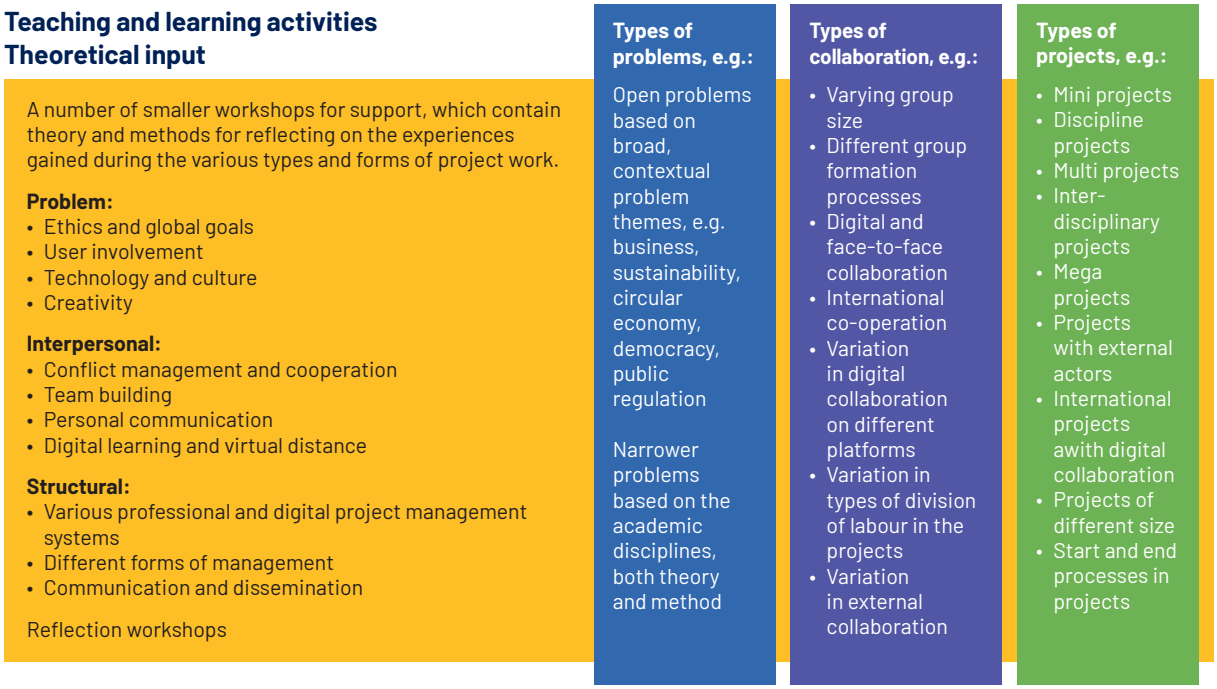

Figure 6. Types of teaching activities for facilitating PBL competencies.

In terms of various types of presentations, the following can be envisaged:

Inspirational presentations (e.g. short lectures or online material)
An inspirational presentation can be attached to a semester's consultant process, which is provided across project groups. These inspirational presentations can be given as oral presentations, by reference to online material or by targeting material prepared for the relevant programme. Material prepared for independent study will be made available in the semester's Learning Management System (LMS), such as Moodle or others.

Themed workshops
Consultants can organise workshops, which go across groups within a given programme. The aim is to initiate a process of developing skills in relation to a specific PBL learning goal and the theme to which this learning goal relates. For example, this might be a workshop on sustainability workshop, conflict prevention and management or on problem-based project work in a company.

Feedback during themed presentation seminars
Consultants can participate in and provide feedback at seminars where students present PBL aspects of their project work within a given theme – for example, using a poster or an oral presentation. There may also be presentation seminars that are planned and facilitated by the consultant team.

Feedback sessions based on project groups' documentation of the project work
This is intended for written feedback or for meetings between a consultant and a group, where a consultant complements the supervisor's expertise within PBL. For example, the starting point could be students' documentation of problem design, assessment of the societal context of problem solutions or oral feedback on process analyses.

Feedback session based on individual students' reflection papers
This is intended for written feedback or for meetings between consultants and individual students about personal development. For example, a session may be based on written reflection papers that are sent to the consultant before the meeting. Possible themes may include individual learning in relation to collective learning, personal learning style or one's own PBL competencies in terms of the future labour market.

Ad-hoc coaching sessions
These may include supervisors inquiring about groups or individuals who have experienced barriers at an inter-personal or personal level in relation to the problem-based project work or the programme as a whole.

3.5 Different types of exams

Learning goals must be assessed with an exam, but they only need to be assessed once in higher education in Denmark. There are various ways in which this can take place:

- At the end of a semester via a course exam, testing whether the students have the prescribed knowledge, skills and competencies within a specific and well-defined field.
- At the end of a semester via a project exam, where there may be written material in the form of a process analysis or other documents and where discussion and presentation of these is included in the exam and counts towards the mark.
- Over the course of a semester, where there may be different types of oral and/or written materials (electronic or on paper) to be passed/approved before the student is allowed to take the exam.
- Finally, at bachelor's or master's exams, where students look back over several semesters to show their metacognitive competencies.

Assessment during semesters is a formative evaluation, where self-evaluations at the individual or group level, as well as formative evaluations of co-operative relationships with external parties, can form the basis for reflection documents that can serve as a basis for assessing the development of PBL competencies in relation to a current situation.

The assessment focusses on progression over several semesters, as is the case for bachelor's or master's exams. It is in accordance with the qualification framework that undergraduate students should be able to identify their own learning needs and structure their own learning in different learning environments, just as master's students must be able to handle interdisciplinary co-operation and be able to take responsibility for their own professional development and specialisation. These are ambitious learning goals that need to be assessed at the end of the students' programmes. The PBL progressive learning goals will have a concrete purpose in supporting students meet this objective in a systematic and qualified manner.

4. SUMMARY

In this guide, we have provided a catalogue of different tools in the planning of problem-based studies. As always, the various tools must be adapted to the specific context, which in this instance means that the tools must be adjusted to the specific skill profile of the programme in question. Similarly, it is always important that there is alignment between the provided learning goals, the organised educational activities and the chosen form of examination.

However, precisely because the problem-based form of learning has such great learning potential, it is also important to provide a meaningful variety in problem-based project work that allows students to address not only a known situation, but also new and often complex situations that require a nuanced understanding of the problem, multi-party involvement and effective project management to remain focused on goals and the selection of the right measures. That is why variety in the way PBL is lived – and variety in practice – is so vital.

In addition, there is an equally important dimension that enables students to make sense of the diverse experiences and use this to rethink established patterns for new situations. Furthermore, this will give students a language through which they can conceptualise their own competencies. This is extremely important in realising that what is unarticulated is harder to communicate to others. Therefore, the link between theory and practice – between the domain specific and the generic – is also absolutely central to qualifying students' PBL competencies.

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